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Short-Term Medical Consequences of the Chernobyl Nuclear Accident: Lessons for the Future

SUMMARY

The author of this article discusses the world's most serious nuclear accident to date: the Chernobyl nuclear accident of April 1986. His major focus is on the short-term medical consequences of the accident, including reduction of exposure to persons at risk, evaluation of persons potentially affected, dosimetry, and specific medical interventions. (*Can Fam Physician* 1988; 34:2565-2570.)

Key words: nuclear accident, Chernobyl, radiation exposure

RÉSUMÉ

Cet article se veut une discussion de l'accident nucléaire le plus grave survenu à date: l'accident nucléaire de Chernobyl en avril 1986. Il insiste particulièrement sur les conséquences médicales à court terme de cet accident, incluant la réduction de l'exposition pour les personnes à risque, l'évaluation des personnes potentiellement atteintes, la dosimétrie et certains actes médicaux spécifiques.

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ON APRIL 26, 1986, the world's most serious nuclear accident occurred at the Chernobyl nuclear power station in the Soviet Union. Details about the accident have been reported by the Soviets, the International Atomic Energy Agency (IAEA), and others.¹⁻⁴ My major focus is on the short-term medical consequences of the accident, including reduction of exposure to individuals at risk,

evaluation of potentially affected individuals, dosimetry, and specific medical interventions.

The Chernobyl Accident

The Chernobyl accident released approximately 50 MCi or 3%-5% of the reactor fuel inventory, along with an equal amount of radioactivity in the form of noble gases into the environment.¹⁻⁴ Twenty-five per cent of the release occurred instantaneously and the remainder over approximately 10 days.¹ Following violent disassembly of the reactor core, a radioactive plume was ejected to a height of up to 10 km above the reactor; winds directed it initially to the northwest so that it skirted the nearby city of Pripyat. Within 36 hours of the accident 45 000 persons were evacuated from Pripyat, which is situated 2-4 km from the reactor. Over the next two weeks approximately

90 000 additional persons were evacuated from 80 to 90 villages within a 30 km radial zone surrounding the reactor.

Evacuation

This accident raised several important considerations relating to the evacuation of populations at risk, such as whether immediate evacuation is always desirable. In the case of Prip'yat, evacuation was postponed until buses were assembled, routes selected to avoid the path of the radioactive plume, and until a polymer film could be sprayed on ground surfaces to reduce the likelihood of inhalation of radioactive dust. Whether this 36-hour delay was entirely intentional is unknown. It was unavoidable to some extent, but the nature of the release and meteorologic conditions may have contributed to some extent to the decision.

For example, only 25% of the release occurred within the initial 48 hours. Moreover the path of the radioactive plume initially missed Prip'yat. Finally, means of individual transportation in the Soviet Union are limited, and so evacuation required public transportation. In the United States individuals would be likely to initiate their own evacuation, using privately owned vehicles.

Another issue raised by Chernobyl is the size and configuration of an evacuation zone. The population of Prip'yat received a lower average radiation dose, 3 mSv, than did persons living at a considerably greater distance from the power station; for example, persons living 3–15 km from the reactor received a dose of 45 mSv.¹ This situation might have been differed considerably had the radioactive plume not been ejected vertically, had the prevailing winds been directed toward Prip'yat, or had all of the radioactivity been released immediately. The circumstances emphasize the need for flexibility in emergency planning and for re-evaluation of evacuation guidelines based on careful review of the Soviet experience at Chernobyl.

Dosimetry

Appropriate medical intervention involves screening of individuals at risk and identification of those most severely affected. Prompt accurate assessment of radiation dose is required in the latter group. There are two basic approaches to dosimetry: physical and biologic. Physical dosimetry by such means as the use of environmental monitoring devices or individual radiation meters or badges, can be of considerable value. At Chernobyl environmental monitoring devices were either destroyed or non-recoverable, and the individual monitoring devices were either not designed for the radiation levels emitted or were destroyed or lost. This is a situation which can be improved on in the future. Remote monitoring of dosimeters is standard at many facilities, and special film badges and thermoluminescent dosimeters are available in case of accidents and are used at many nuclear reactors.

Because of the factors mentioned, biological dosimetry was used at Chernobyl.^{5–8} This dosimetry in-

involved serial determination of levels of lymphocytes and granulocytes in the blood, and analyses of dicentric chromosomes in spontaneously dividing and phytohemagglutinin-stimulated hematopoietic cells in blood and bone marrow. The interval from radiation exposure to onset of nausea or emesis was also considered. Calculation of dose was based on data relating these parameters to dose in prior radiation accidents.⁸ By using these variables it was possible to estimate the dose of radiation received.⁹ (Baranov AE, Gale RP, Guskova E, et al, manuscript in preparation). The Poisson distribution of cytogenetic abnormalities suggested uniform whole-body exposure in most instances. Analysis of ²⁴Na levels in the victims indicated the absence of a detectable neutron component of the radiation exposure.

Medical Interventions

Diverse medical interventions are required to respond to radiation accidents, the range of which depends on the spectrum of injuries and concordance of toxicities. It is predicted that accidents at different types of reactors, such as graphite-moderated or pressurized water reactors, will result in different spectrums of injury. Concordance of toxicities complicates the nature and effectiveness of medical interventions. Consequently, it is not possible to devise a single medical plan for all accidents or to draw conclusions about the value of different medical interventions from a single accident. The United States should be prepared to respond to the full range of potential accidents, modifying the medical plan to specific conditions.

Acute exposure to high-dose total body radiation results in three major syndromes. At the highest dose (>50 Gy) central nervous system (CNS) damage results in death within minutes to one to two days. Doses of approximately 10–15 Gy can produce death from gastrointestinal tract damage within one to two weeks. The bone marrow is the major target of doses between 5 and 15 Gy; as a result death can occur within two to six weeks. These syndromes are not discrete, and there is considerable overlap of toxicities. The precise dose at which these syndromes occur is affected by additional factors, includ-

ing radiation dose, schedule and route. Different types of radiation, too, produced different patterns of toxicity. β -radiation causes primarily local effects, Γ -radiation local and distant effects; neutron radiation causes more tissue damage than comparable doses of β or Γ . α -particles are also particularly destructive to tissues.

The major elements in the medical response to radiation accidents include treatment of skin burns and measures designed to correct or reverse bone-marrow failure and gastrointestinal injury. Damage to the lungs, the liver, and other organs and tissues must also be considered. Analysis of the effects of radiation on these tissues and organs is complex, a situation made very plain by the Chernobyl accident. Supportive measures such as protective isolation, gastrointestinal tract decontamination, antibiotics, transfusion of blood products, and intravenous hydration and alimentation are essential.

Most of the Chernobyl victims received a dose of whole-body radiation compatible with bone-marrow recovery in the context of intensive supportive measures. Patients were kept in isolation; some were maintained in sterile laminar air-flow environments. Antibiotics and antiviral drugs such as acyclovir were administered. Extensive transfusions were also necessary, including red blood cells and platelets; the latter were obtained from normal donors as well as by plateletpheresis using sophisticated blood-cell separators. Some patients received autologous cryopreserved platelets.¹⁰ These blood products should be irradiated prior to transfusion to prevent inadvertent engraftment and induction of graft-versus-host disease.

In some instances the dose of radiation received may be associated with a high likelihood of irreversible bone-marrow failure; in this circumstance other interventions, such as bone-marrow transplantation, should be considered. The objectives of bone-marrow transplantation after radiation exposure are complex. At low doses, transplants of histo-incompatible hematopoietic stem cells are typically rejected without a deleterious effect. At mid-lethal doses, transplants of histo-incompatible hematopoietic stem cells are associated with

Good night...

decreased survival in mice but not in dogs or monkeys.¹¹⁻¹³ This adverse outcome, termed the "midzone effect", is associated with graft rejection; it occurs by means of a poorly understood mechanism.

At higher doses of total body radiation, transplants of histo-incompatible hematopoietic stem cells can improve survival by means of several mechanisms. In some instances temporary engraftment permits recovery of endogenous hematopoiesis.¹³⁻¹⁵ This effect is observed only in histo-incompatible transplants when T-cells are removed from the bone-marrow inoculum; failure to carry out this procedure results in fatal graft-versus-host disease. If the bone marrow is irreversibly destroyed by radiation, sustained hematopoietic engraftment is a prerequisite of survival.

The question of which individuals should receive bone-marrow transplants is complex. The initial strategy is to include individuals in whom the dose of total-body radiation is associated with a high risk of death from bone-marrow failure and to exclude individuals likely to die of non-

hematopoietic toxicity such as skin burns or pulmonary damage. This strategy is not easily accomplished, particularly when there are overlapping toxicities, some of which may not be immediately apparent.

Next, one must determine whether a histo-compatible donor is available. Potential donors include related, partially or fully HLA-identical relatives, or an HLA-identical unrelated individual identified in an HLA-typed volunteer donor pool. The feasibility of this latter approach was tested at Chernobyl when three potential unrelated donors were identified within three to four days. Another possibility is the use of fetal liver-derived hematopoietic stem cells.^{16,17} Transplantation of fetal liver cells is successful in mice and dogs; evidence of efficacy in humans is less convincing.

Transplantation, although of potential benefit, is not without risk. The balance of risks and benefits must be carefully considered and will differ between accidents with different spectrums of injury, as well as between individuals within a given accident.

In view of the magnitude of the Chernobyl accident, one might have expected a substantial immediate loss of life. Fortunately, this did not occur; two persons were killed instantaneously; 500 persons were hospitalized. More than 200 persons received a dose in excess of 1 Gy, and more than 35 a dose exceeding 5 Gy. The postulated 50% lethal dose of total-body radiation within 60 days in humans is 4.5 Gy.^{18,19} Most individuals received the supportive measures discussed, including 13 persons who received bone-marrow transplants and six who received infusions of fetal liver cells. Twenty-nine persons died from radiation-and/or heat-induced injuries over the following three months, including 11 bone-marrow transplant recipients and the six fetal liver-transplant recipients. Most of these deaths were from skin burns or damage to other organs such as the gastrointestinal tract or lungs. The remaining persons are reasonably well and have been discharged from hospitals.

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Chernobyl accident, since a number of factors beyond control served to reduce the number of immediate injuries. These include the direction of the radioactive plume; the prevailing meteorological conditions, including wind direction and absence of precipitation; the timing of the accident; and the fact that the total release occurred over nine to 10 days rather than instantaneously.

Conclusions

What conclusions can be drawn about the immediate medical consequences and response to nuclear accidents? In some ways, medical interventions were quite successful, despite the complexities described. Intensive supportive care was associated with a high rate of survival of most persons who received <6 Gy total-body radiation. In the absence of a prospective randomized trial, it is not possible to know what proportion of these persons would have survived if no treatment had been given. Nevertheless, it is highly likely that these supportive measures, such as the administration of systemic antibiotics and platelet transfusions saved lives.

It is more difficult to evaluate the efficacy of these measures in individuals receiving >6 Gy total-body radiation. Several of these patients received transplants. Although some experimental data suggest that autologous bone-marrow recovery in this setting may relate to T-cell-depleted transplants, some persons who received a comparable dose of total-body radiation without transplant also survived. It may be concluded that bone-marrow transplants can rescue only a small proportion of victims of radiation accidents; irreversible damage to other organs is likely to limit the success of this approach. In addition, many individuals lack a suitable donor, a limitation that can be overcome by using HLA-typed volunteer donor registries or by progressing in the use of partially histocompatible related donors. Recent advances in the ability to remove T-lymphocytes from the graft and thereby to modify graft-versus-host disease may increase this likelihood.^{20,21} The decision as to whether a bone-marrow transplant is indicated, like most therapeutic strategies, requires a critical analysis of

the potential benefits and risks for each individual.

Clearly the factors that limit the efficacy of medical intervention following a nuclear accident would be multiplied extraordinarily in the context of a nuclear war. In such a setting it is difficult to conceive of an effective medical response.^{22,23}

There are several important lessons to be learned from Chernobyl about immediate medical effects. First, nuclear accidents are far more complex than imagined. Another is the effectiveness, as well as the limitations, of immediate medical interventions. Many of these interventions were highly effective at Chernobyl. A third is that humans can survive a considerably greater radiation dose than anticipated. This last discovery is scarcely surprising in view of recent advances in supportive care, antibiotics, and transfusions.

Future Directions

What directions should future research take in this field? Although transplantation of hematopoietic stem cells can facilitate hematopoietic recovery, it is associated with several complications. Transplantation is probably not required for persons receiving <8 Gy total-body radiation. It may be possible to expedite bone-marrow recovery in these persons by using molecularly cloned hematopoietic growth factors.²⁴ Preliminary data in mice, in monkeys, and in humans suggest that this approach may be successful.

Individuals exposed to >8 Gy may not recover bone-marrow function but may retain sufficient immunity to reject transplants. This difficulty can be overcome by effecting additional immune suppression by drugs or radiation. Preliminary data in dogs suggest that this approach can be successful.¹³ T-cell-depleted transplants may be useful in some circumstances. Although nuclear industry workers should not have their bone marrow cryopreserved, HLA-typing might be considered. This approach would have the added benefit of providing a pool of highly motivated HLA-typed individuals who might be willing to donate bone marrow or platelets for persons with leukemia or aplastic anemia.

In medicine, prevention is always considered superior to treatment. By

analogy, nuclear accidents must be prevented. Unfortunately, this is not possible with current reactor technology. In fact, some recent analyses suggest a 25% or higher risk of a major accident somewhere in the world within the next 10 years.²³ The risk of a core meltdown in the United States within the next 20 years is variably predicted at 2% to 20%.²³ Because the risk of accidents cannot be reduced to zero with current technologies, the development of "inherently safe" fission or fusion reactors must be a long-term goal if nuclear energy is to continue to be used or its use expanded.

Perhaps the two most important lessons of Chernobyl are that nuclear energy is not inherently good or evil, but that its quality is contingent on the way in which society uses it, and that nuclear energy anywhere is a nuclear energy everywhere.

We live on a small planet; civilization is likely to benefit if we and the Soviets work together in these sophisticated and potentially dangerous technologies. This includes working together to reduce the likelihood of nuclear war. ■

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